"On usage of coupled neutron-kinetic and thermal-hydraulic computer code DYN3D+ATHLET to study safety of VVER-1000 type reactors under transient and emergency operational modes"

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Presently, increased requirements are imposed to study transient and emergency operation modes of nuclear facilities from point of view of quality and adequacy their simulation. In particular, concerning the Ukrainian NPPs this is connected with that analysis of VVER-1000 safety for a whole number of design basis accidents in the Technical Substantiation of Reactor Facility Safety requiring spatial-kinetic modeling was performed on the base of reactor core kinetic calculation in point approximation which did not allow to estimate maximum possible value of power fuel pin load releasing during emergency process.

Below this work addresses the first experience gained under usage of coupled neutron-physical and thermal-hydraulic computer code DYN3D+ATHLET [1] for safety analysis of Ukrainian NPPs with VVER-1000 on the base of the transient calculation connected with the switching off one of four working main circulation pumps (MCP) at the 6-th unit of Zaporizhya NPP. Internal coupling of DYN3D with the ATHLET is used in these calculations.

Since experiment on switching off MCP in the 1st loop of reactor core cooling system was performed after 43.6 effective days of unit operation, then in advance spatial distribution of fuel burn-up was calculated for this moment by DYN3D code. Later on it was used in the coupled version of DYN3D+ATHLET program complex for simulation of this transient. In DYN3D neutron-physical calculation reactor core was represented in sixty degree symmetry with subdivision of the core into 10 layers in the axial direction. Switched off cooling loop was modeled by separate one, while the rest three – by generalized one. One channel core model is implemented in the ATHLET code.

Due to the MCP in the 1st cooling loop was switched off during experiment, reactor power was reduced from 76.8% down to 51.8% of the rated level with the use of power restrictor, in accordance with the regulation. Steam pressure was stabilized with the use of turbine regulation system. Reactor power was reduced by insertion of the working group (10th group of CPS control rods) into the core with the rate of 2 cm/s.

Under the early calculations performing it was revealed that due to lack in the ATHLET input file detailed description of the turbine regulation system successful modeling of this experiment was impossible. Therefore, in calculations the pressure

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inside the main steam header (MSH) was assigned as the boundary condition into ATHLET input file. This is presented in Fig. 1. In order to get the stable initial conditions before the transient calculation the zero-transient calculation was performed. Table 1 presents the comparison between calculational reactor core parameters obtained after 500 seconds of zero-transient calculation and measured data.

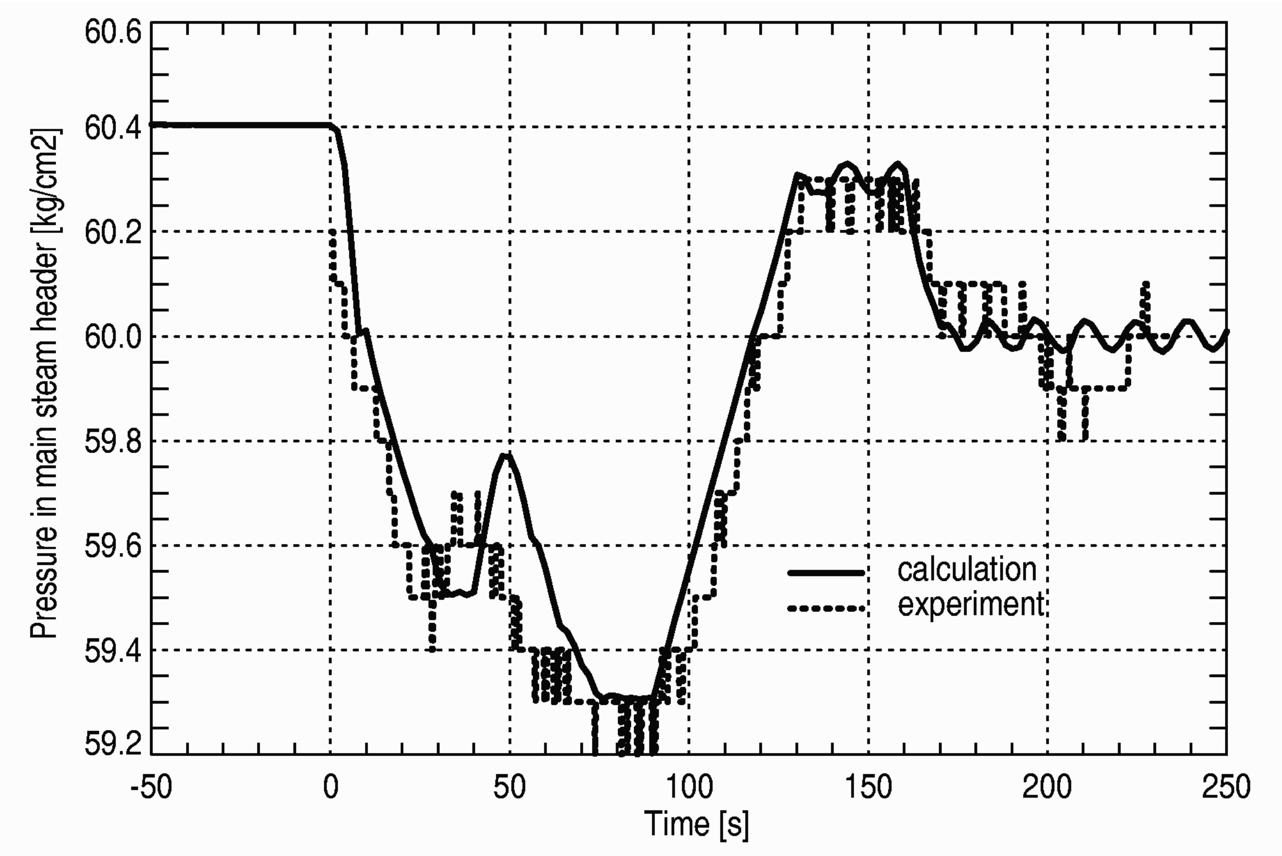

Figure 1. Main steam header pressure

Table 1

Comparison between the results of zero-transient calculation and experimental data

Parameter	Value	
	Experiment	Calculation
Thermal power, MW	2292	2291.7
Full power days	43.6	43.6
Boric acid concentration C_B, g/kg H_2O	6.0	5.6
10-th control rod position (from core bottom), %	79	80
Average cold leg temperature, °C	285.2	283.8
Average hot leg temperature, °C	307.5	307.5
Core coolant heating, °C	22.3	23.7
Pressurizer level, cm	787	787
Upper plenum pressure, kg/cm^2	159.1	159.1
Main steam header pressure, kg/cm^2	60.4	60.4

Working group movement was adjusted by power controller modeled in the ATHLET. At that time, according to the experimental conditions, reactor power unloading level was assigned as 52% from the rated value. Difference between experimental and calculated values for position of the 10^{th} group of CPS control rods by the end of experiment (see Fig.4) can be explained by the deviations concerning value of calculating and experimental efficiency. Under insertion of CPS control rods of working group into core with rate of 2 cm/s time behaviour of neutron power and reactivity (see Figs. 2 and 3) is influenced by control rods absorber movement between the interfaces of two successive axial layers (so-called cusping effect). After the 80 seconds of the transient, fluctuations of power and reactivity are explained by periodical movement of the working group connected with simulation of power controller. Behaviour of the primary pressure and water level in the pressurizer (see Figs. 5 and 6) correlate satisfactorily with the appropriate measured values.

There are evident deviations between calculation and experiment concerning the cold and hot leg temperatures (see Figs. 7 and 8). First of all, it should be said that just at the initial stationary condition the value of temperatures measured in four loops deviate from each other. This difference is stipulated by asymmetry of cooling loops which in these calculations could not be taken into account, since different conditions in loops (deviations of pump characteristics) were unknown, while in the calculation as such modeling of three loops with pumps operated was performed via addressing of one generalized loop. Deviation between average values of measured and calculated temperature in cold legs at initial condition is $1.5 \div 2$ K and, presumably, is stipulated by difference of coolant mass flow rates. Unfortunately, measured value of the coolant mass flow rate is unavailable in the experimental data concerning this transient. Deviations between calculated and measured value of temperatures in hot legs can be explained by that coolant mass flow rate in switched off loop (counter-flow is available) is overestimated (loop with counter-flow has the lower temperature of hot leg than in experiment), while in core – underestimated. Here it should be noted that resistance of pump through which counter-flow occurs is also, regretfully, unknown.

Pressure and water level in the steam generator, by calculation, are of the same trend as in experiment (see Figs. 9 and 10). At that time, it should be noted that there are differnces for them between calculated and experimental values.

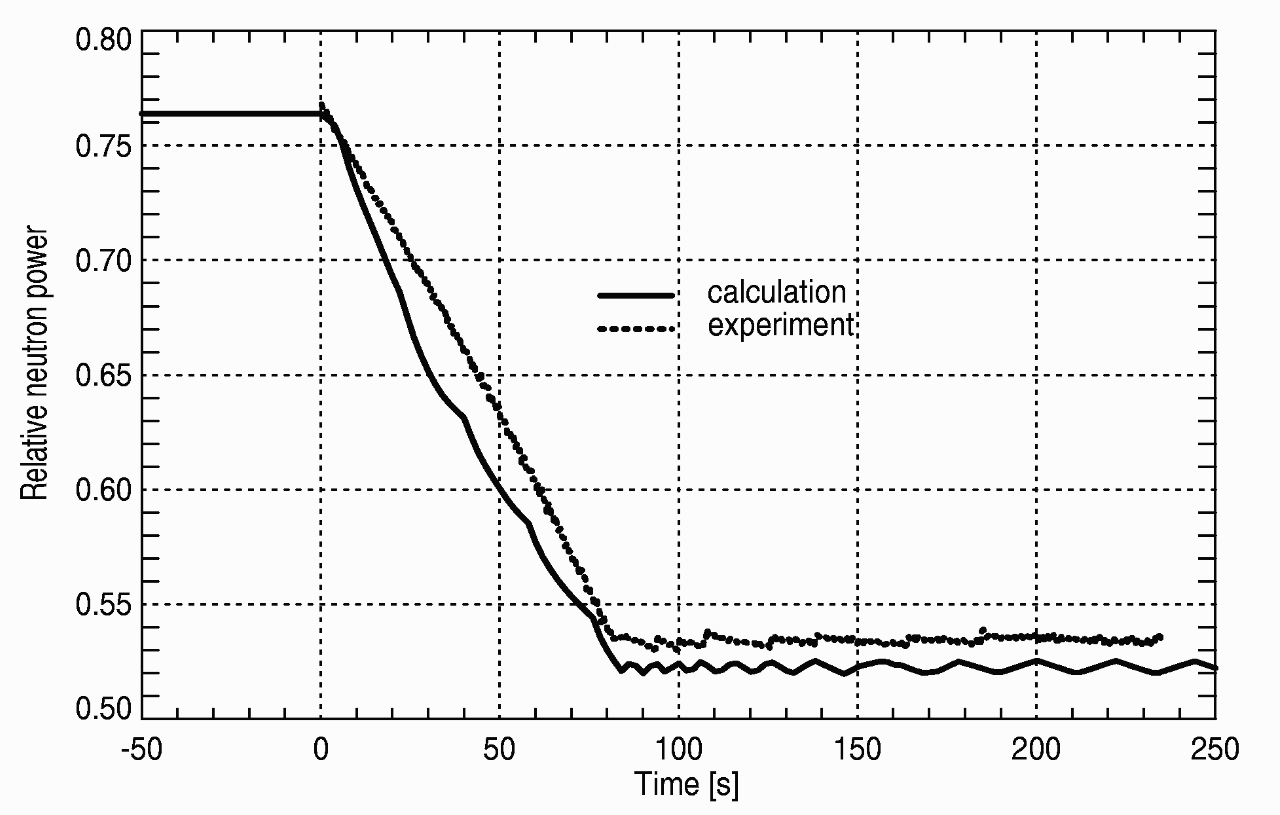

Figure 2: Relative neutron power

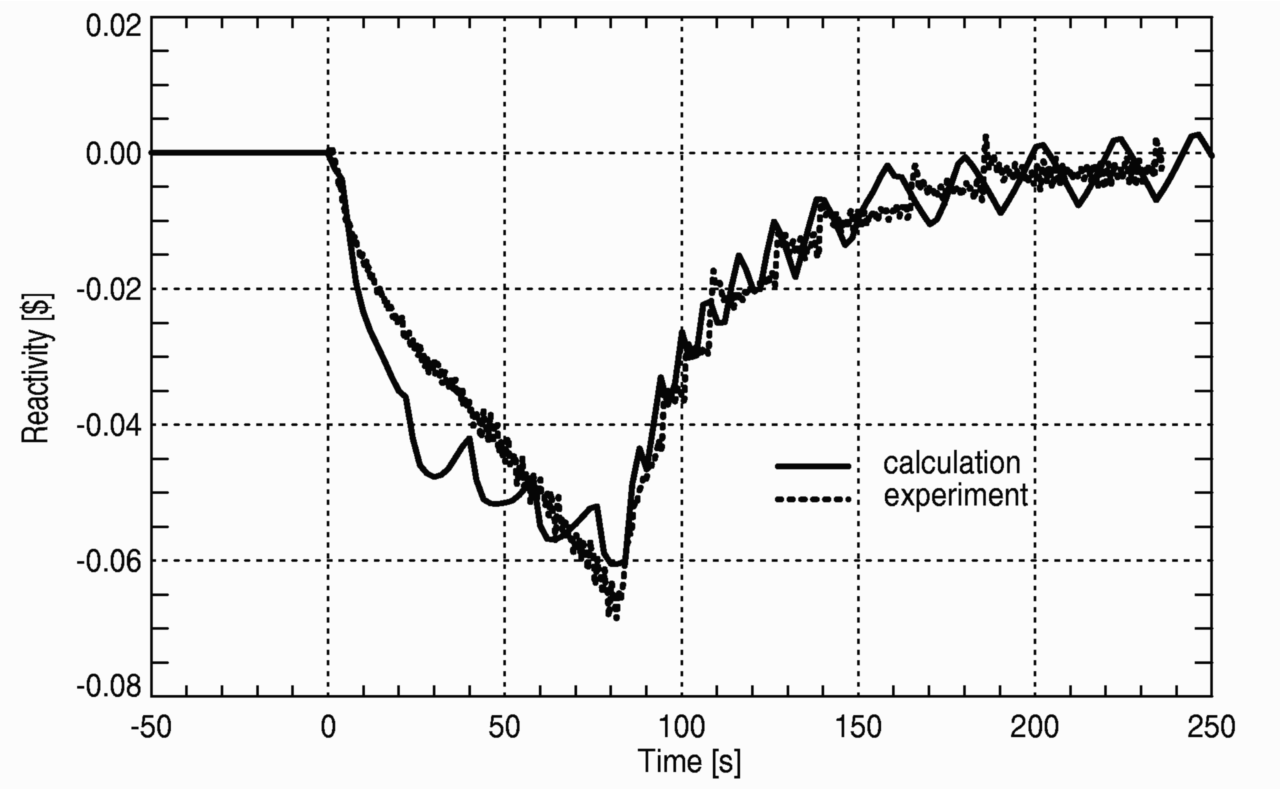

Figure 3: Reactivity

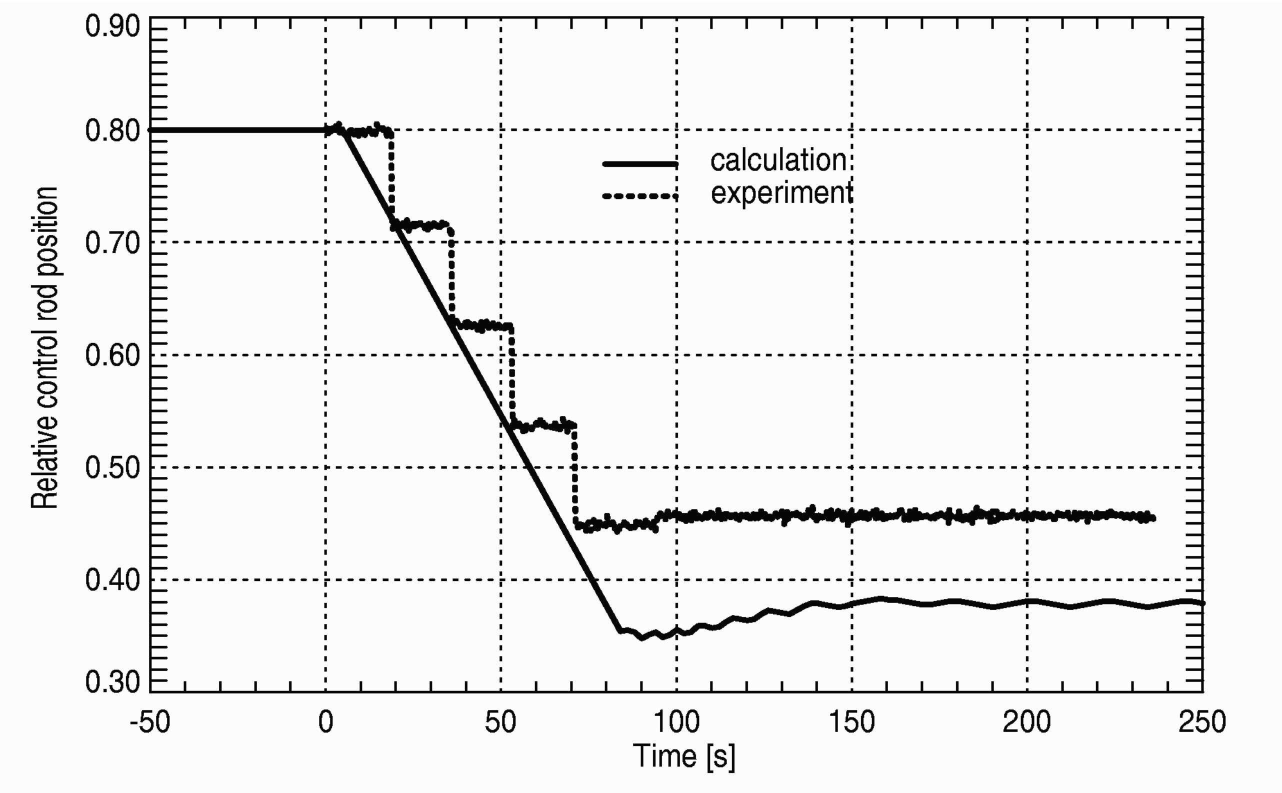

Figure 4: 10-th control rod group position

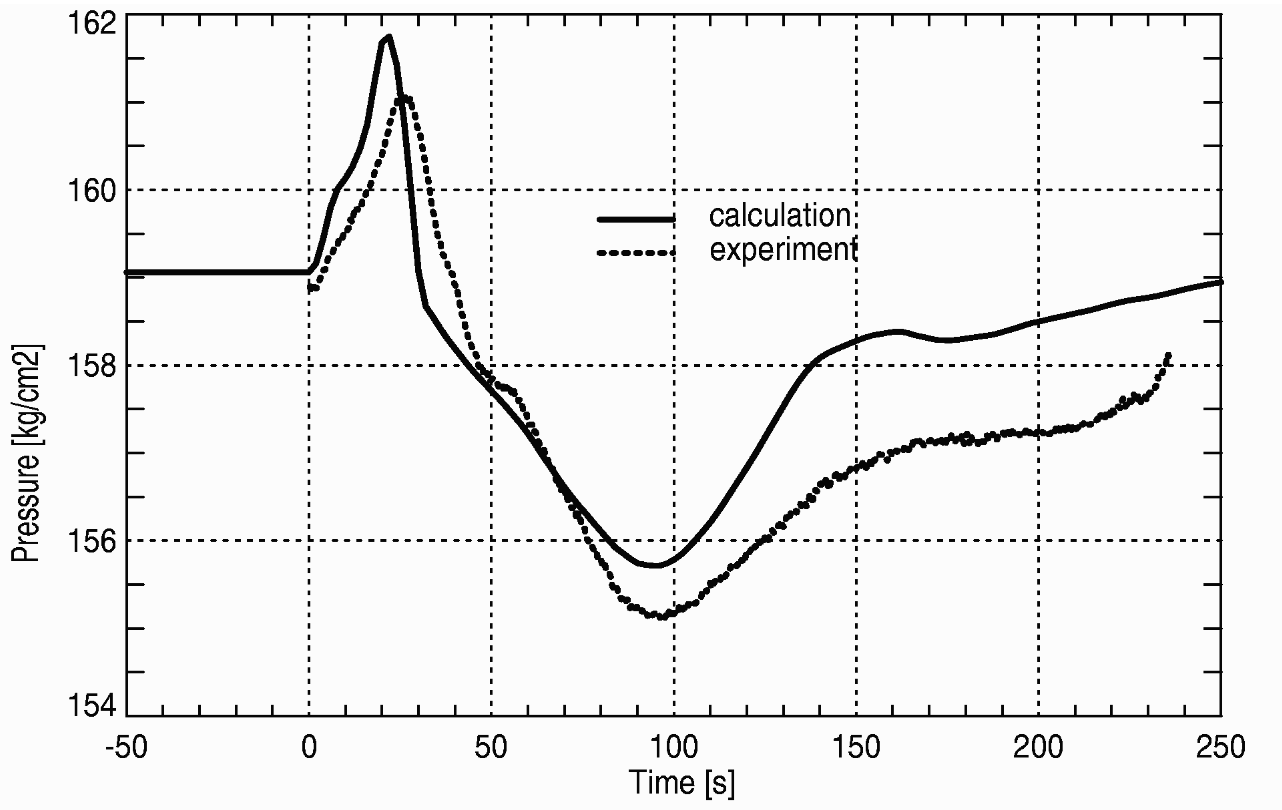

Figure 5: Upper plenum pressure

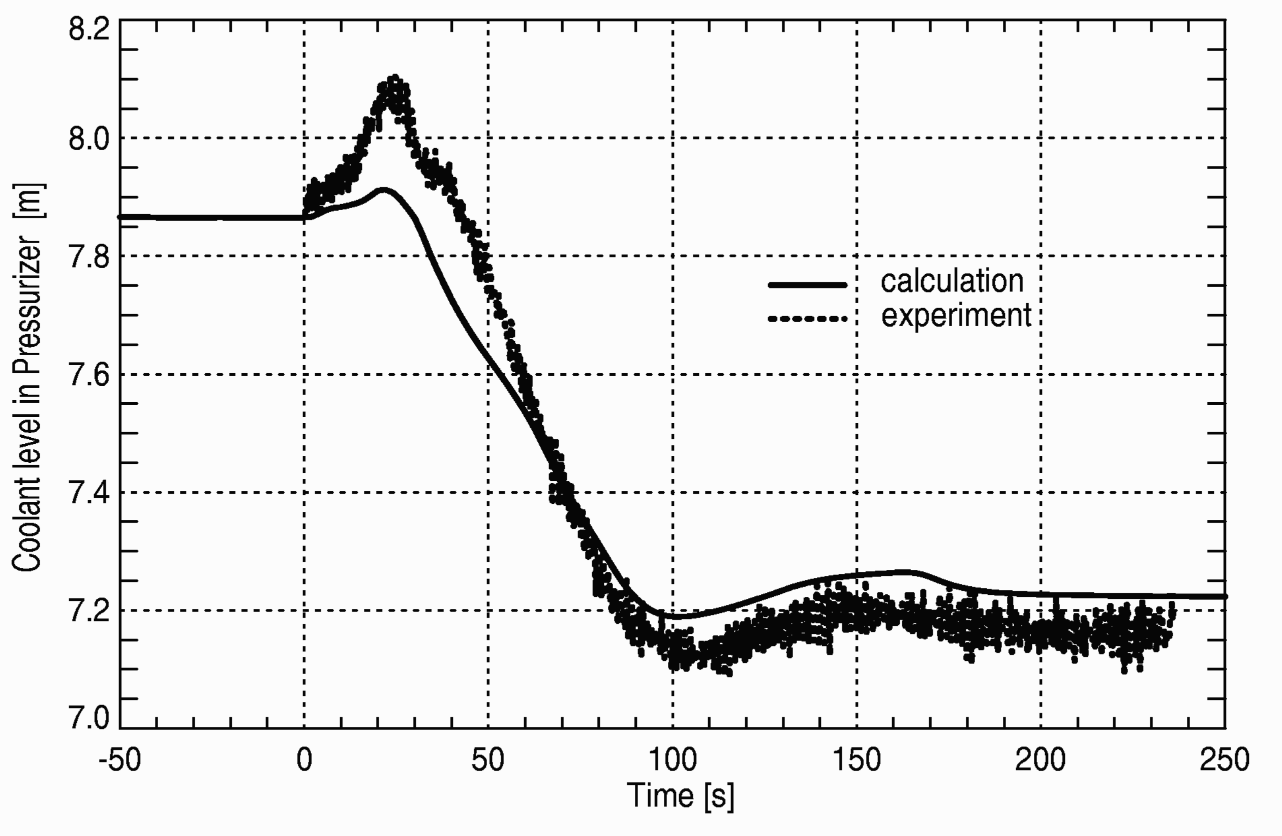

Figure 6: Water level in pressurizer

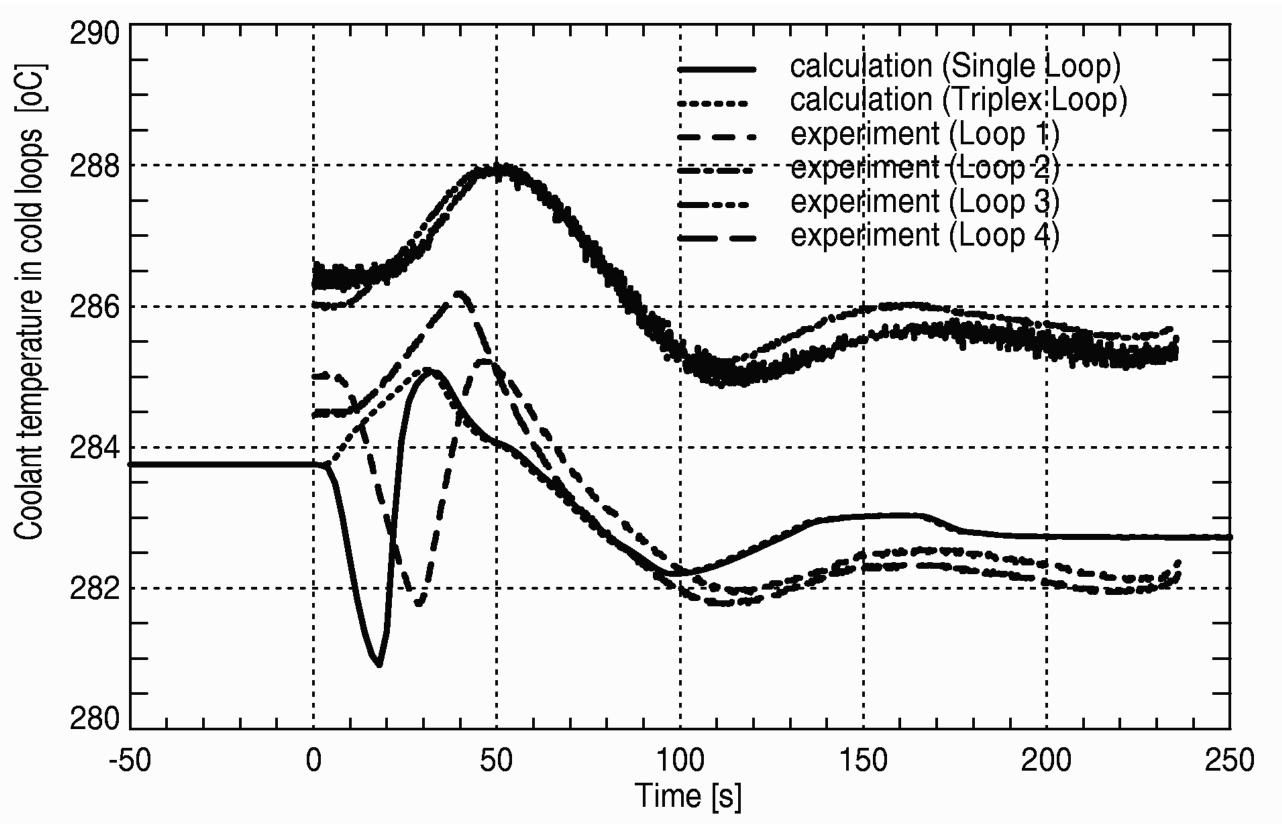

Figure 7: Cold legs temperature

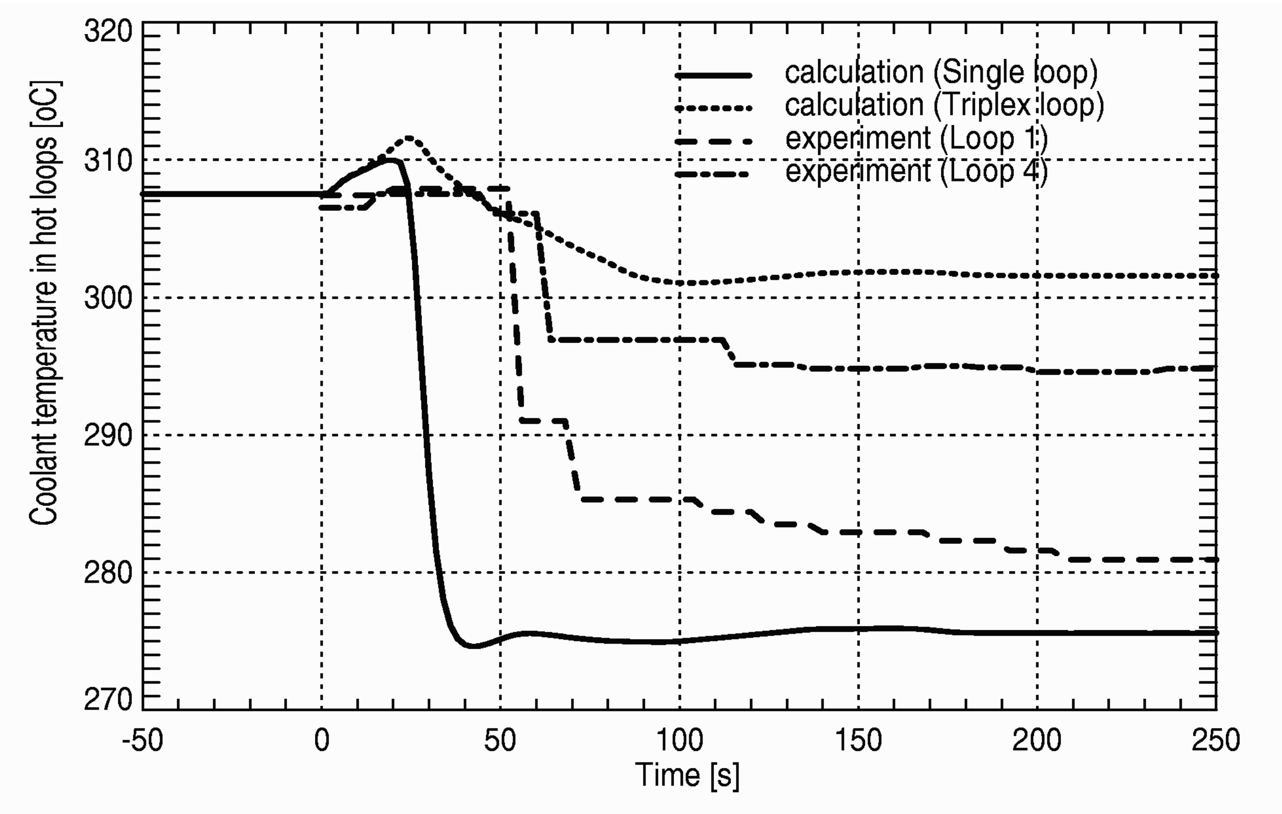

Figure 8: Hot legs temperature

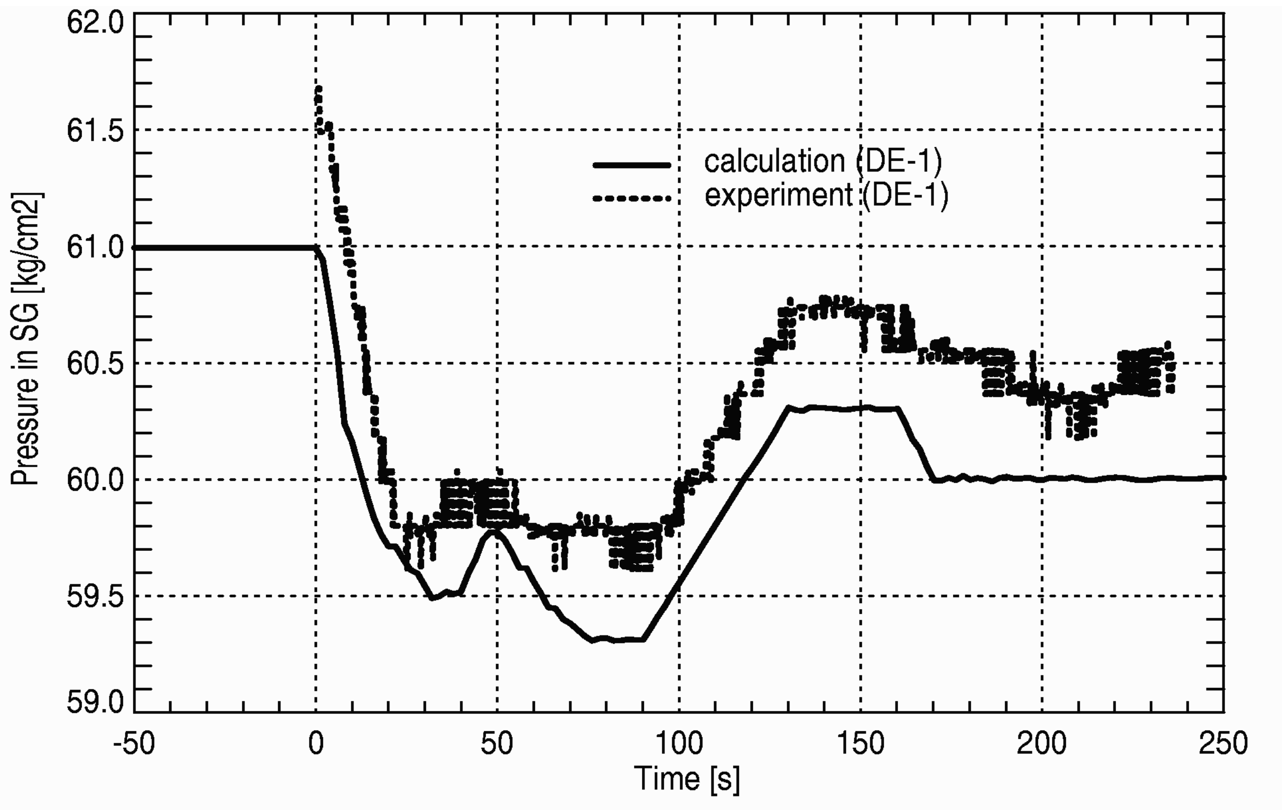

Figure 9: Steam generator pressure in the switched off leg

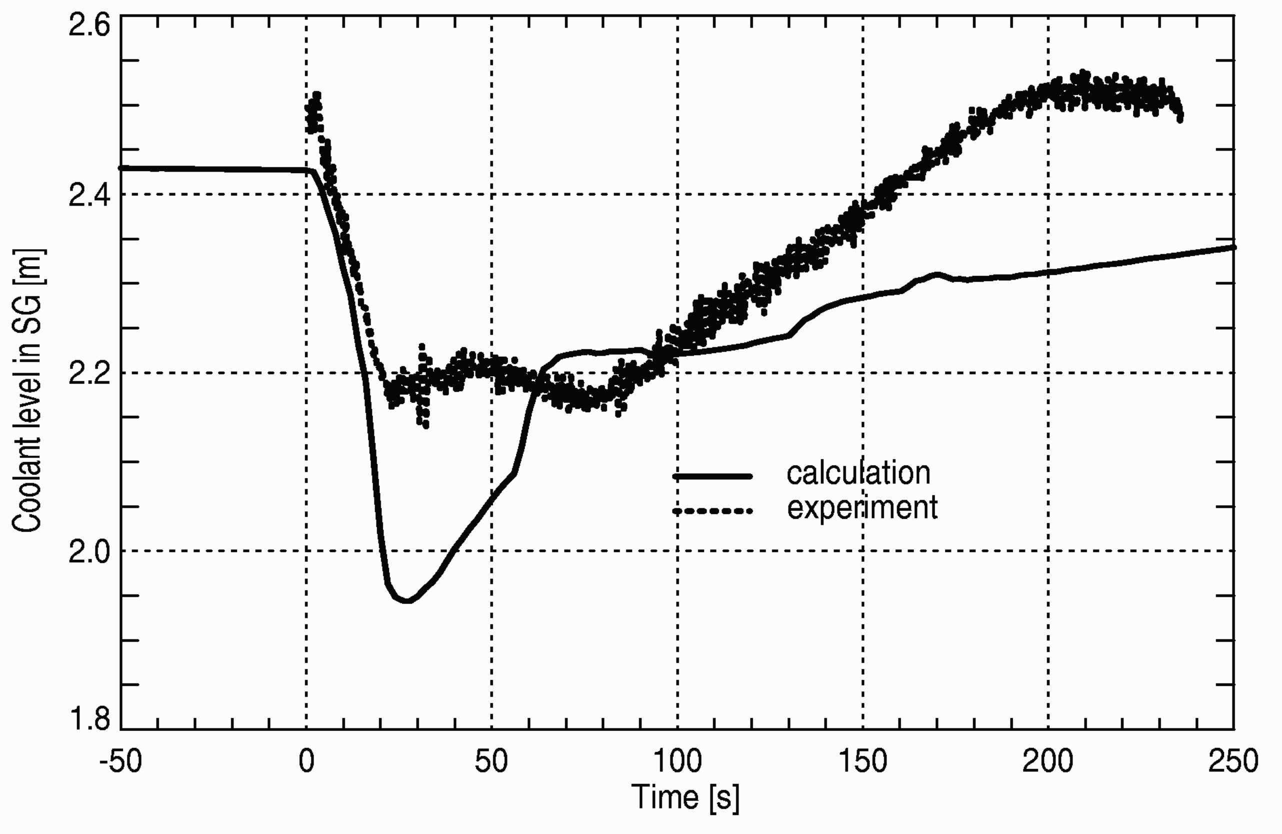

Figure 10: Steam generator water level in the switched off leg

References

1. Grundmann U., Kliem S., Lucas D., Rohde U., Coupling of the thermohydraulic code ATHLET with the 3D neutron kinetic core model DYN3D. Proceedings of the sixth Symposium of AER, Finland, September 23-26, 1996, p. 179-191.